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A more extended account of the investigation will be published in the near future.

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[1] Barnett, S. J., *Physic. Rev., Ithaca, N. Y.*, (Ser. 2), 6, 1915, (239–270).

[2] Einstein, A., and de Haas, W. J., *Berlin, Verh. D. Physik. Ges.*, **17,** 1915, (152–170, 203, 420).

[3] de Haas, W. J., *Amsterdam, Proc. Sci. K. Akad. Wet.*, **18,** 1916, (1281–1299); *Sci. Abs., London,* A., **17,** 1916, (351).

THE INTENSITIES OF X-RAYS OF THE L SERIES

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The purpose of this paper is to report briefly some preliminary results of a study of the intensities of X-rays belonging to the L series of platinum considered as functions of the potential producing them and in their relations to each other and to the general radiation.

Review of Previous Work.—Many of the phenomena observed here can be predicted, though with no certainty, by analogy with corresponding phenomena of the K series. The similarity of the two series appears in Moseley's laws[1] of frequency as a function of atomic number, and especially in the fact that each series is produced as fluorescence by a substance absorbing rays of a higher frequency. It has been found by one of us[2] that the K series rays, of rhodium at least, appear only at a potential high enough to produce general radiation of a frequency as great as that of the shortest line of the series. This may be called the critical potential. Since this result is obviously connected with the law that absorbed rays will produce the K fluorescence only if their frequency is above that of this line, it is reasonable to expect a similar law for the L series.

It must be remembered, however, that the L series is more complex than the K, both in the number of lines and in their gradual shifting relative to each other from element to element, shown in Moseley's graphs[1] of square root of frequency against atomic number of the emitting element. Moreover Kossel[3] has found reason to believe that platinum and gold each show two discontinuities of absorptive power as a function of frequency near the L series, one in the middle of the series and the other near the high frequency end. An explanation of this appears in a most exhaustive study of the positions of the L series lines of the heavy elements by Siegbahn and Friman[4] who have plotted $\sqrt{\nu}$ against N for twelve lines. Four of these graphs are linear and nearly parallel, while the eight others are not linear but are nearly parallel with a greater slope than the four. This suggests that the four, α_2, α_1, β_2, and β_5, (see fig. 1) form one series, which we shall call L_1, while the others, η, β_4, β_1, β_3, γ_1, γ_2, γ_3, and γ_4, form another series, L_2. The L_1 series is remarkably similar in appearance to the K series, unless we include in it the line *l*, reported by Siegbahn in a paper which is not yet accessible, but which is quoted by Friman.[5] From this similarity one would expect the L_1 series to have a critical potential equal to the quantum potential of its highest frequency member, β_5. The L_2 series, on the other hand, is totally different in appearance so that similar predictions can scarcely be made. The existence of two series accounts readily for that of two discontinuities of absorption.

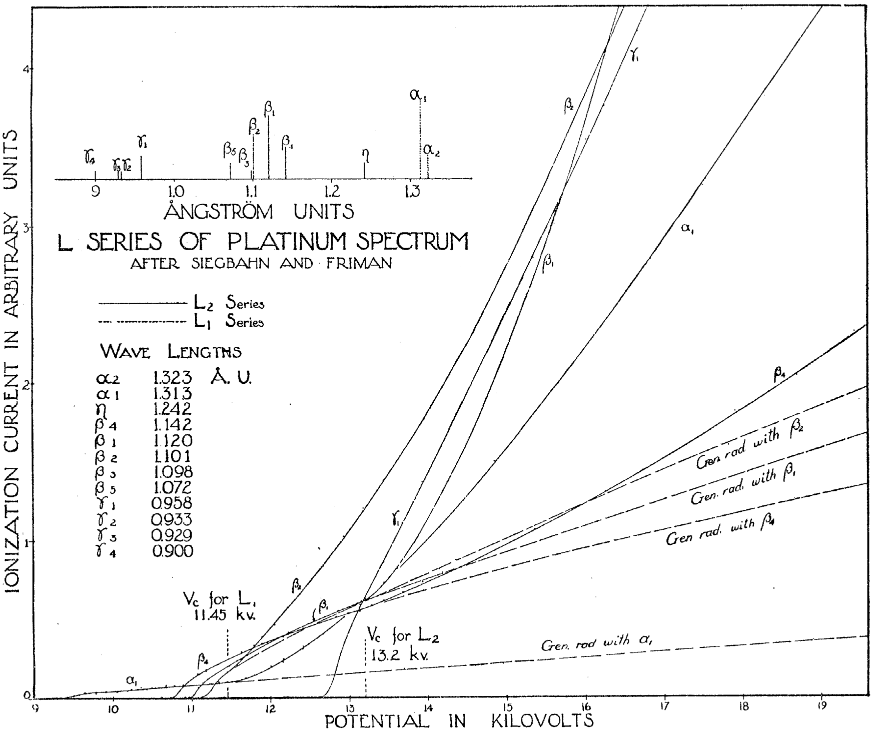

FIG. 1.

Following farther the analogy with the K series, one might expect all lines of each of the L_1 and L_2 series to increase in intensity by the same ratio with any given increase of potential,[6] and we may expect their intensity-potential graphs to be concave upward, while that of general radiation of any one frequency starts concave downward and soon becomes linear.[7]

Results of Our Experiments.—We have partially tested these predictions for a platinum target in a Coolidge tube furnished through the kindness of Dr. Coolidge. The potential was obtained from Professor Trowbridge's 40 kv storage battery, and measured by a Chaffee electrostatic voltmeter calibrated by a manganin resistance of 0.8940 megohms. The spectrometer was similar in general plan to that used in the previous work on rhodium, but with many improvements in construction and accuracy.

The principal results of the work to date are shown in figure 1, which contains graphs of intensity as a function of potential for two lines, α_1 and β_2, of the L_1 series and three lines, β_4, β_1, and γ_1, of the L_2 series. In each case the graph leaves the axis at the potential required to give an electron an energy quantum of the proper frequency, and each graph is of the form of one for general radiation only, from the start to a definite potential at which its curvature suddenly changes. This change denotes the first appearance of the spectrum line. For both the L_1 lines, this change occurs at 11.45 kv., or the quantum potential of the β_5 line, as predicted, within the limits of error caused by the uncertainty in h. For β_4 and β_1 also the critical points are identical, but quite different from that of the L_1 lines. In none of these four cases can there be any doubt as to the existence of critical points, although the intensities are somewhat inaccurate, since even β_1 is so weak there that a fall of the electroscope over the shortest scale division requires about half a minute.

In the interpretation of the γ_1 curve, difficulty arises from the fact that the critical point is so close to the quantum potential that the general radiation itself has not acquired a uniform rate of increase. This curve has therefore been repeated in figure 2, with curves for general radiation of wave lengths just above and below γ_1. From these the general radiation with γ_1, itself may be estimated. It is represented by the dotted line, which crosses each of the other curves at about the proper distances and would lie midway between them at very high potentials. From these graphs it appears that γ_1 also has a critical potential, identical with that of β_1 and β_4, which appears to be 13.20 ± 0.05 kv. The wave length corresponding to this potential is 0.937Å, not that of γ_4, the predicted head of the series, but even longer than γ_2. This result, which was quite unexpected, raises a question as to the nature and behavior of the three very faint lines γ_2, γ_3, and γ_4, on which we hope to obtain more evidence in the course of this work.

The calculations of the critical wave lengths of the series is dependent on the value assumed for Planck's *h*. Millikan's experiments on photoelectrons give 6.57 × 10^{-27} erg sec., while the value obtained in the work on rhodium was 6.53. The latter value was obtained from the potential at the middle of the sharp upward curvature at the foot of each graph and is subject to any errors that may occur in determining this potential. This is made uncertain by the width of the slit and consequent lack of homogeneity of the rays. If, for example, the graph for really homogeneous rays turns down very sharply to the axis, and the boundaries of the rays used are made indefinite by the size of the source, the potential to be used should be that of the steepest part of this curve. This hypothesis seems highly improbable since the maximum angle between any two rays coming through the slit is under 0.10 in this case, giving less than ½% deviation of any reflected wave length from the mean, and the steepest part of the curve occurs about 1% from the lowest potential at which any rays can be detected. Consequently we shall follow the method of calculation previously used. The values of *h* obtained are given in table I. Siegbahn and Friman's

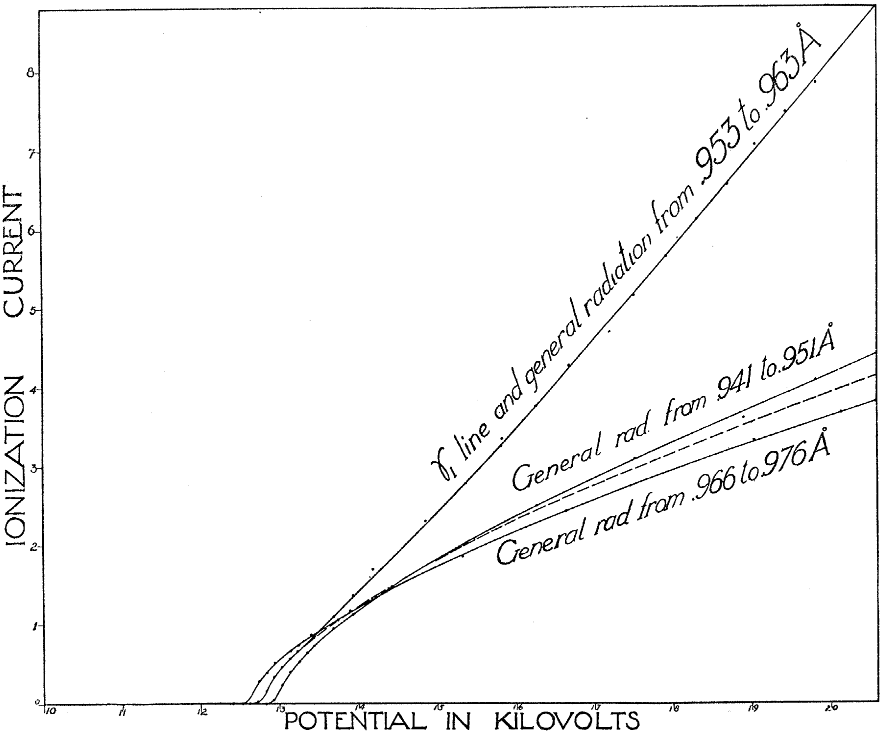

FIG. 2.

wave lengths are used as standards. Whatever constant errors there may be in this determination of h will cancel out in the calculation of the critical wave lengths.

TABLE I

Line	λ	h (erg sec)
α_1	1.313Å	6.59×10^{-27}
β_4	1.142	6.53
β_1	1.120	6.54
β_2	1.101	6.53
γ_1	0.958	6.48
Mean		6.53

The intensities of the lines alone may be obtained by subtracting from the ordinates of their graphs the general radiation estimated as in figure 1. By this process it appears, as expected, that lines of the same series maintain the same ratio of intensities through any increase of potential up to 20 kv., the limit of our experiments to date. For potentials over 20% above the critical points, the mean deviation of these ratios from their average values is less than 3%. More accurate results should be obtained at higher potentials and with more exact determinations of the general radiation. The graphs both of lines and general radiation are also of the general forms predicted. Present results indicate that the rhodium K series and platinum L_1 and L_2 series all increase in intensity approximately in proportion to the three-halves power of the difference between the potential applied to the tube and the critical potential of the series. On all these points, however, the present statements are only preliminary, and more accurate results should be obtained from further work now being done on platinum. Since the relation between the two series is different in different elements, we hope to test these phenomena in thorium also.

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[1] *Phil. Mag., London,* (Ser. 6), **26**, 1913, (1024–34); **27**, 1914, (703–14).

[2] These PROCEEDINGS, **2**, 1916, (90–4); *Physic. Rev., Ithaca, N. Y.,* (Ser. 2), **7**, 1916, (599–613).

[3] *Berlin, Verh. D. Physik. Ges.,* **16**, 1914, (898–909).

[4] *Phil. Mag., London,* (Ser. 6), **32**, 1916, (39–50).

[5] *Ibid.,* **32**, 1916, (497–499).

[6] *Ibid.,* **26**, 1913, (210–232), see especially p. 225.

[7] The instrument was made from our design by the Alvan Clark Corp., Cambridge, Mass.